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**CPRF/ZTH FRONT-END TORUS DESIGN
AND FABRICATION STATUS**

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CPRF/ZTH FRONT-END TORUS DESIGN AND FABRICATION STATUS[†]

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ABSTRACT

Design of the ZTH front-end torus has been completed for a new generation Reversed Field Pinch (RFP) machine to be assembled at Los Alamos National Laboratory during FY 92. The Confinement Physics Research Facility (CPRF) houses the ZTH front-end torus. The ZTH torus consists of an Inconel 625 vacuum vessel supported by an external electrically conducting 304L stainless steel shell. Interspace support rings support the vacuum vessel to the shell and also provide accurate radial support for the interspace electrical diagnostics. The shell also supports 48 toroidal field coils that are mounted to the shell's external surface.

The shell consists of an explosion bonded stainless steel-copper composite with water-cooling tube assemblies attached to the outer surface. The 0.135-in. thick copper is on the inside surface of the shell, and provides an electrically conducting path with the required electrical time constant of 50 ms. The shell plate will be formed to the required toroidal configuration, after which the poloidal and toroidal flanges will be welded to the structure and machined.

The Inconel vacuum vessel consists of bellows segments, armor support rings, and diagnostic stations welded together to form the complete vacuum vessel assembly. The necessity for accurate positioning of the vacuum vessel within the shell requires that the shell and vacuum vessel be fabricated with major diameter tolerances within 0.050 in. true position of the nominal diameters of 188.0 in. and 188.820 in., respectively.

INTRODUCTION

Design of the ZTH front end torus was completed for a next step Reversed Field Pinch (RFP) machine to be assembled at the Los Alamos National Laboratory during FY 92. This experimental fusion research machine designated the ZTH experiment, will be housed in the Confinement Physics Research Facility (CPRF). Figure 1 shows the ZTH torus in its present configuration assembled on the bottom bulkhead support structure. For clarity, the diagnostics platform that surrounds the outer periphery of the machine is not shown.

The ZTH torus, shown by Fig. 2, consists of an internal Inconel 625 vacuum vessel that contains the high temperature plasma. The vacuum vessel is protected by a graphite armor system consisting of 5652 tiles attached with dovetail clips to the armor support rings in the vacuum vessel. The vacuum vessel is designed to support external atmospheric and magnetic pressure loads of approximately 185 psia. Since the vacuum vessel is constructed with 112 bellows segments, it must be supported in the toroidal direction. This loading condition is supported by the surrounding stainless steel shell through the interspace support rings attached to the outside of the vacuum vessel armor support rings.

The vacuum vessel also has fifteen diagnostic stations at 22.5° intervals. The sixteenth station is inside the poloidal field insulating gap and cannot be used for diagnostic access. Diagnostic access

Fig. 1. ZTH Front-End

Fig. 2. ZTH Torus

with the fifteen available stations consists of 124 ports of various diameters. Two of the thirteen 5.0 in. diameter ports on the horizontal midplane will be used for vacuum pumping initially, with two more pump stations added later. The shell segments are also at 22.5° intervals and have openings to accommodate the 124 ports protruding from the vacuum vessel. Figure 3 shows a shell module with diagnostic ports protruding through the shell openings. Toroidal field coils are also shown attached to the shell surface.

[†] Work performed under the auspices of the US DOE.

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Fig. 3. ZTH 7M1 Shell Module Assembly

Fig. 4. ZTH Shell segment with TF coil and brackets.

DISCUSSION

A shell segment with toroidal field coil and brackets is shown in Fig. 4. The shell is a 0.75-in. thick, 304-L stainless steel plate with 0.135-in. thick OFHC copper explosion bonded to the inside surface to provide an electrically conducting path with the required electrical time constant of 50 ms. Water cooling is provided by a tube assembly attached to the outer surface.

The principal loads supported by the shell are the vacuum vessel magnetic pressure loads exerting a net load radially inward, the toroidal field coil radial inward loads and the overturning moment loads from the toroidal field coils.

A flat pattern will be cut from explosion bonded plate and the shell segments will be formed to the required toroidal configuration. The poloidal and toroidal flanges will be welded to the structure and then final machined after stress relieving. The required tolerances are to be achieved in the as fabricated condition without relying on additional machining. Figure 5 is a cross section through the shell showing the position of the water-cooling tubes and the toroidal field coil support brackets and radial adjustment feature.

Figure 6 shows the Inconel 625 vacuum vessel weldment. The vessel consists of 112 bellows segments, 128 armor support rings, and sixteen diagnostic stations. The vessel will be made in two 180° halves to enable installation of the internal graphite armor at Los Alamos. The vessel will be assembled into the shell at the fabricators location to assure that the assembly will go together before shipment to Los Alamos. Helium leak checking will be performed at the normal bakeout temperature of 300°C at the fabricators location to assure that the vessel is leak tight. After installation of the armor, thermal insulation, and electrical diagnostics at Los Alamos, the final two

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Fig. 5. ZTH Shell Cross section with toroidal field coils installed

diagnostic stations will be welded into the vessel to complete the assembly.

The major diameter of the shell is 188.000 ± .025 in. with the major diameter of the vacuum vessel of 188.860 ± .025 in. at the 200°C operating temperature. This results in the required Shafranov radial offset of 0.430 inch. Figure 7 is a top view with the top shell half removed to show the positioning of the vacuum vessel and interspace support rings within the shell bottom half.

The necessity for accurate positioning of the vacuum vessel within the shell, based on the plasma flux surface, requires that the shell inside copper surface be fabricated to a profile tolerance of 0.040 inch relative to the nominal 36.290 in. minor diameter. This tolerance will be difficult to obtain, but must be maintained in the as fabricated condition because the copper inner surface cannot

Fig. 6. ZTH Vacuum Vessel Weldment

Fig. 7. Vacuum vessel positioning within the shell structure

be machined due to a thickness uniformity requirement of 0.135 ± 0.010 inch. Careful fabrication techniques must be employed, but discussions with fabricators indicate the tolerances will be possible to achieve.

The poloidal field gap is a special shell module occupying the space of a standard 22.5" shell module, but provides an insulating current break in the toroidal direction. The gap consists of three overlapping electrically insulated conductors, with the inner and outer at a voltage potential up to 12.5 kV different than the center conductor. The conductors consist of 304 L stainless steel plate with OF HC copper explosion bonded to the surface. The copper on each conductor requires a taper along the entire length to provide the required current distribution in the gap to minimize magnetic field errors. Polyurethane film provides the primary electrical

insulation between the conductors with fiberglass pre-preg used as the structural filler between the conductors. The gap is a very complex component and must also meet the specified tolerances in the as-fabricated condition without relying on final machining operations.

The vacuum vessel is also a difficult fabrication objective, since the major diameter must be held to a close tolerance. The vessel will be made up of bellows module and diagnostic station subassemblies which will have been previously fabricated and inspected to close tolerances. These subassemblies will be accurately fixtured in an assembly fixture to maintain the overall assembly tolerances as the assembly progresses. The as-fabricated dimensions for the shell and vacuum vessel assemblies will then be used to custom fit the interspace support rings onto the OD of the vacuum vessel armor support rings. The vacuum vessel assembly will then be assembled into the shell structure to assure proper fitup.

SUMMARY

The design of the front-end shell, poloidal field gap, vacuum vessel, interspace support structure, and front-end assembly fixtures was completed. A request for proposal was issued April 4, 1989, with proposals and cost estimates due August 3, 1989. The proposals were reviewed by a proposal evaluation committee and rated on the basis of technical capability. A contract will be issued and work will begin in the near future.